TESTING AND SPLICING ELECTRIC CABLES AND FRAME-GROUNDING PIT EQUIPMENT, TECUMSEH COAL-STRIP MINE, BOONVILLE, IND.

By Sanford J. Douglas

* * * * * * * * * * * * information circular 7995

UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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TESTING AND SPLICING ELECTRIC CABLES AND FRAME-GROUNDING PIT EQUIPMENT, TECUMSEH COAL-STRIP MINE, BOONVILLE, IND.[1]

by

Sanford J. Douglas[2]

SUMMARY AND INTRODUCTION

This publication describes a study by the Federal Bureau of Mines of devices and methods used for testing and splicing 4,160-volt and 440-volt cables and for providing ground-fault protection for 440-volt circuits, as developed and used by the electrical staff of the Tecumseh coal mine, an open-pit operation at Boonville, Ind.

The testing and ground-fault devices described should find ready application in other open-pit mines, and, with suitable modifications for voltages involved, in underground mining. The devices and testing methods are based on sound engineering principles and are time-tested and economically feasible.

Four devices are used: A high-voltage tester, and a low-voltage high-current tester, both for testing 4,160-volt cables; a tester for 440-volt cables; and, electronic ground-fault protective device for 440-volt cable circuits. All the cable testers and the grounding device were designed and built at the mine from standard parts. They are inexpensive, dependable, and job tested. An attempt has been made here to describe them in enough detail so that interested persons can assemble duplicate units.

The splicing methods followed at Tecumseh mine, especially the use of the nylon-ply wrapper, should also find ready application at any mine where moisture and mechanical strain are factors. This would include most underground coal mines. The usual methods followed in coal mines in making temporary electrical splices can be improved by using nylon-ply wrapped slices (assuming good workmanship is used throughout), which are far superior. For underground mining, the characteristics of mechanical strength, adequate insulation, and water-resistance afforded by the temporary splicing methods used at the Tecumseh mine would provide a decided advantage against shock, fire, and explosion hazards. Also, such techniques would prolong the life of cables and minimize downtime of equipment.

1/ Work on manuscript completed May 1960.

2/ Coal-mine inspector (electrical), Bureau of Mines, Vincennes, Ind.

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The maintenance staff of Tecumseh mine considers that the nylon-ply wrapper used plays a key role in its highly successful program of trouble-free cable maintenance. However, a consistent effort to locate and repair cable faults before they cause trouble or become dangerous is probably the basic reason for success. Ingenuity in devising testers that will locate most types of cable faults made achievement of the goal possible. Finally, the electronic ground-fault protector plays an important part. The success of the described devices and methods must, therefore, be viewed as the result of a well-integrated program. Others could adapt parts of the Tecumseh program to their operations without adopting all of it.

Alternating-current power is used throughout the Tecumseh operation, except that it is rectified within the larger machines, in accordance with widespread strip-mine practice, to provide for use of direct-current motors and controls where such have advantages in torque, sensitivity, and other operating characteristics. The present discussion applies only to alternating-current systems serving portable pit equipment at strip mines. The splicing methods, however, appear adaptable to cables, at both underground and strip mines, for alternating- or direct-current equipment. The low-voltage tester has wide application. The principles involved in the high-voltage tester and in the low-voltage, high-current tester, could be used for testing almost any cable, provided modifications are made to use components of lower values for lower voltage cables.

ACKNOWLEDGMENT

Acknowledgment is made to Merle Guthrie, mine superintendent, and Chester Brown, mine electrician, for making this paper possible. Mr. Brown supplied all the technical information and developed the device and practices described.

GENERAL INFORMATION

The Tecumseh mine, in Warrick County, Ind., south of State Highway No. 68 and 4 miles east of State Highway No. 61, is a coal-stripping operation owned by Peabody Coal Co.

POWER SYSTEM

Power is purchased at 36,000 volts and transformed to 4,160 volts to supply stripping and loading units and transformers, which reduce potential to 440 volts for smaller units such as pit pumps and drills. The 4,160-volt power is distributed by wire-armored, 4/0-sized cables, which are laid on the ground, sectionalized in 500- and 1,000-foot lengths, connected in splice boxes, and eventually terminate in strategically located switchhouses.

From each switchhouse, a 500-foot section (termed a "drop") of 2/0 rubber-jacketed cable is extended toward the pit and terminated in a splice box, to which the trailing cables of the stripping and the loading shovels can be connected. These drop and trailing cables are type SH-D. Trailing cables are 1,000 feet long; size 2/0 is used for the stripping shovel, and Nos. 4 and 6 for the loading shovel. All loader cables now purchased are No. 4, chiefly

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for added mechanical strength. To facilitate exchanging sections and dead-heading the shovels, all type SH-D cables for 4,160-volt service are connected by one standard-size molded rubber plug. As the plug becomes slightly worn, it is removed from stripper-shovel service and used for the lower current-demand loader-shovel service. First cost is thus compensated for by double life and the benefits of standardization.

GROUNDING

Grounding of 4,160-Volt Secondary System

The secondary 4,160-volt circuit is wye-connected, with midpoint grounded through a current-limiting impedance; it is provided with a ground circuit tripping arrangement to open all three phases. The grounding conductors and shielding of the SH-D cables are used for frame grounding, and the ground circuit is continued through the three grounding conductors and the armor of the wire-armored cables to the transformer bank. This grounding arrangement is effective and adequate, but it has no unique features, as do the other practices described herein.

Grounding of Low-Voltage (440-Volt) Alternating-Current Equipment

Frame grounding the low-voltage equipment is accomplished at Tecumseh by an electronic device, which, with improvements, has been in constant service several years. The installation requires only one unit per power transformer bank (fig. 1); this single unit will protect all equipment on that transformer bank from phase-to-frame faults. Phase-to-phase faults and overcurrent situations are handled by circuit breakers or primary fuses.

This electronic ground protective system is applied to ungrounded power-distribution systems only, and the described unit is for 440-volt alternating-current use, but the principle might be applied to systems of lesser voltage. The parameters of the system are such that when a phase conductor comes into contact with a machine frame, the voltage rise from frame to ground will be less than 50 volts and is usually less than 10 volts. Values permit a man standing in water, who might chance to grasp any one of the three phases, to escape with only a painful shock and slight burns, which is unique protection. It is not recommended that this method of proving the effectiveness be tried; experience at Tecumseh amply proves the effectiveness, and the operation and sensitivity of the device can be checked by simple but safe means.

The system uses a magnetically operated circuit breaker and three-conductor, type W, trailing cables. If at any time the total resistance to ground of the cable system, motors, controllers, and other components falls below approximately 15,000 ohms, an electronic unit removes the power from the system instantly and holds it off as long as the total resistance is less than 40,000 ohms. When the total resistance to ground reaches a point above 40,000 ohms, the power is returned to the system after a delay of 3 or 4 seconds. This delay is introduced so that in the event a person should accidentally come into grasping contact with any one phase to ground, he will have time to unclasp.

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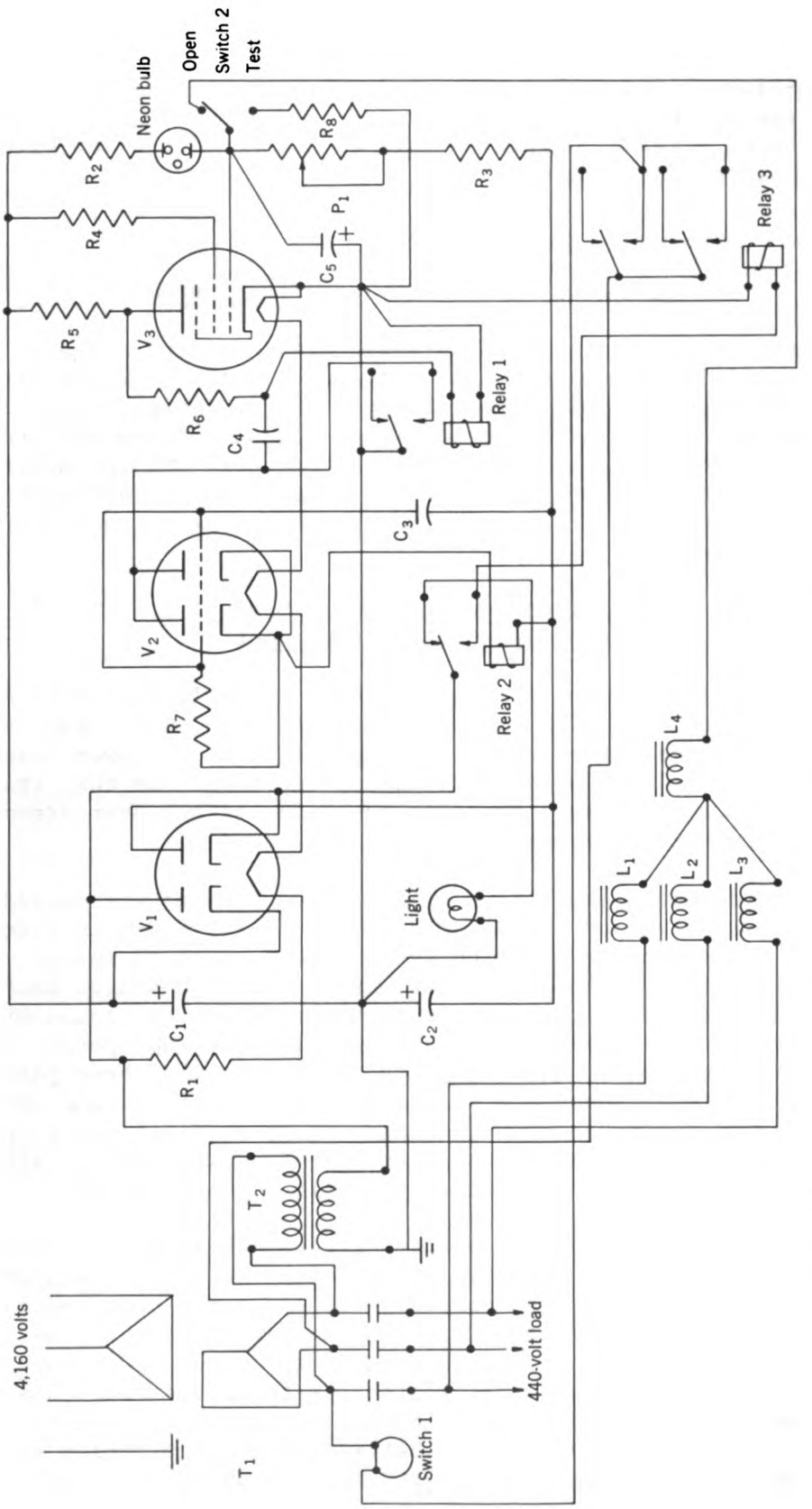

FIGURE 1. - Electronic Ground Detecting Device. Note: The device is equally effective with secondary of 440-volt power transformer connected delta.

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This grounding system is very sensitive and is particularly sensitive to water grounds. The trailing cables and other wiring must be kept in excellent condition to keep power in the system. This is one of the chief advantages of the device from both operating and maintenance standpoints. At Tecumseh mine it is thoroughly feasible and practical to maintain cables in the required condition by means described later, so that protection against shock is achieved by a corresponding improvement in overall efficiency of mining operations. Normal moving of trailing cables gives almost a daily check on the conditions of the fault protective system and conditions of cables. Besides, the effectiveness of the protective system can be checked easily by purposely grounding a phase in the pit, with loss of power for only a few seconds.

The three-phase power transformer is connected delta/wye, or wye/delta (4,160/440 volts); the primary and secondary windings are ungrounded. The incoming high-voltage-system ground is tied to the transformer frame. The 440-volt secondary is controlled by a magnetically operated switch, the holding coil of which is controlled by the electronic ground detecting device. An electrical midpoint, common to the three phases, is established by line chokes in each phase, with the "cold" sides brought to a common tie point. This circuit, common to the three phases, is connected to the grid circuit of the control tube. When a ground fault occurs on the secondary system, this grid circuit is shorted towards ground; the holding-coil circuit of the main magnetic switch is opened, and power is removed from the load.

Voltage regulation of the device allows the unit to operate on supply voltages ranging from 100 to 140 volts, with approximately 5-percent variation in tripping resistances.

Advantages of Electronic Ground-Fault Protector

The complete unit (except the main magnetic switch) is 8 by 11 by 7-1/2 inches and is easily installed. Parts are standard over-the-counter type, and the entire unit is inexpensive, compared to some currently used systems of frame grounding.

The system has no direct ground connection with the 4,160-volt-system ground. This factor eliminates the possibility of lethal feedbacks from this high-voltage ground and also eliminates the possibility of lightning-stroke surges being transferred from the high-voltage ground to the 440-volt equipment through a tie-in to a 440-volt ground conductor.

The device operates on voltage; the tripping current required is in the range of a few milliamperes, so that a person could accidentally grasp a line phase and the tripping current would not be fatal. On conventional current-actuated systems such an act would be fatal, and the conventional system would still not open because of high tripping amperages required.

Insulation punctures or bare splices can be detected easily by inserting the suspected cable in a waterhole; when the faulty section of cable touches the water, the power goes off.

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Eliminating a ground conductor in the trailing cable reduces the physical size, cost, and weight of the cable. Splices are simpler, faster, and cheaper; and the possibility of the fourth conductor being inadvertently spliced to a phase conductor or not spliced at all is eliminated.

The primary of the power transformer and the power for the magnetically operated power-switch holding coil are each connected to different phases of the 440-volt system, thus affording single-phase protection at the transformer (although not for cables and mining equipment).

No part of the load system (cables, controller, motors) can burn from high-resistance grounds and render connectors and other components unsafe.

Due to the sensitivity of this system, trailing cables must be kept in a much better condition than with conventional grounding systems. This results in far greater safety, as cables are safer to handle, and splices are better insulated. Equipment wiring does not require any special attention; if in any equipment the line-to-frame resistance falls to 10,000 ohms or lower, repairs are needed anyway.

This system is impractical for higher voltages and extensive cable systems where the system capacitance is very large, but it should work well on any ungrounded strip or underground-mine electrical system up to 440 volts a.c.

The electronic ground device might appear to be too sensitive (as is often the case in similar devices), so that it would trip on almost nonexistent phase-to-ground faults, stray ground currents, and other causes, resulting in long downtimes in the detection and repair of such small faults. At Tecumseh mine, however, where these devices have been in use for several years, after the electronic ground detectors were installed and the cables checked and repaired, very little downtime was experienced.

CABLE TESTING

Equipment and Procedure for Testing Insulation of 4,160-Volt Cables

All high-voltage cables, both wire-armored and SH-D are periodically subjected to a high-voltage test for effectiveness of conductor insulation, and to a low-voltage, high-current test for continuity and adequate current-carrying capacity of ground conductors. Any section of cable that faults in service or fails the test is immediately replaced, and the faulted section is repaired. Pretested replacement sections are kept available, but, should such replacement not be available, the faulty cable section is repaired (described later) before operation of equipment is resumed. Makeshift cable repairs are not permitted.

High-Voltage Tester

This unit is compact (11-1/2 by 8-1/2 by 7-1/4 inches), relatively light (19-1/2 pounds complete with test leads), and the utmost in operational

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simplicity. The entire assembly is housed in a plastic case, and no metal parts are exposed other than the alligator clamps on the ends of the test leads. It develops an output of 30 kilovolts across a capacitance of 0.4 microfarad. The circuit (fig. 2) is of the voltage-doubler type, in which the low-amperage, high-voltage output of the rectifier is stored in capacitors; the output of the capacitors is fed into the cable under test by two well-insulated test leads. The unit is powered by 110 volts alternating current.

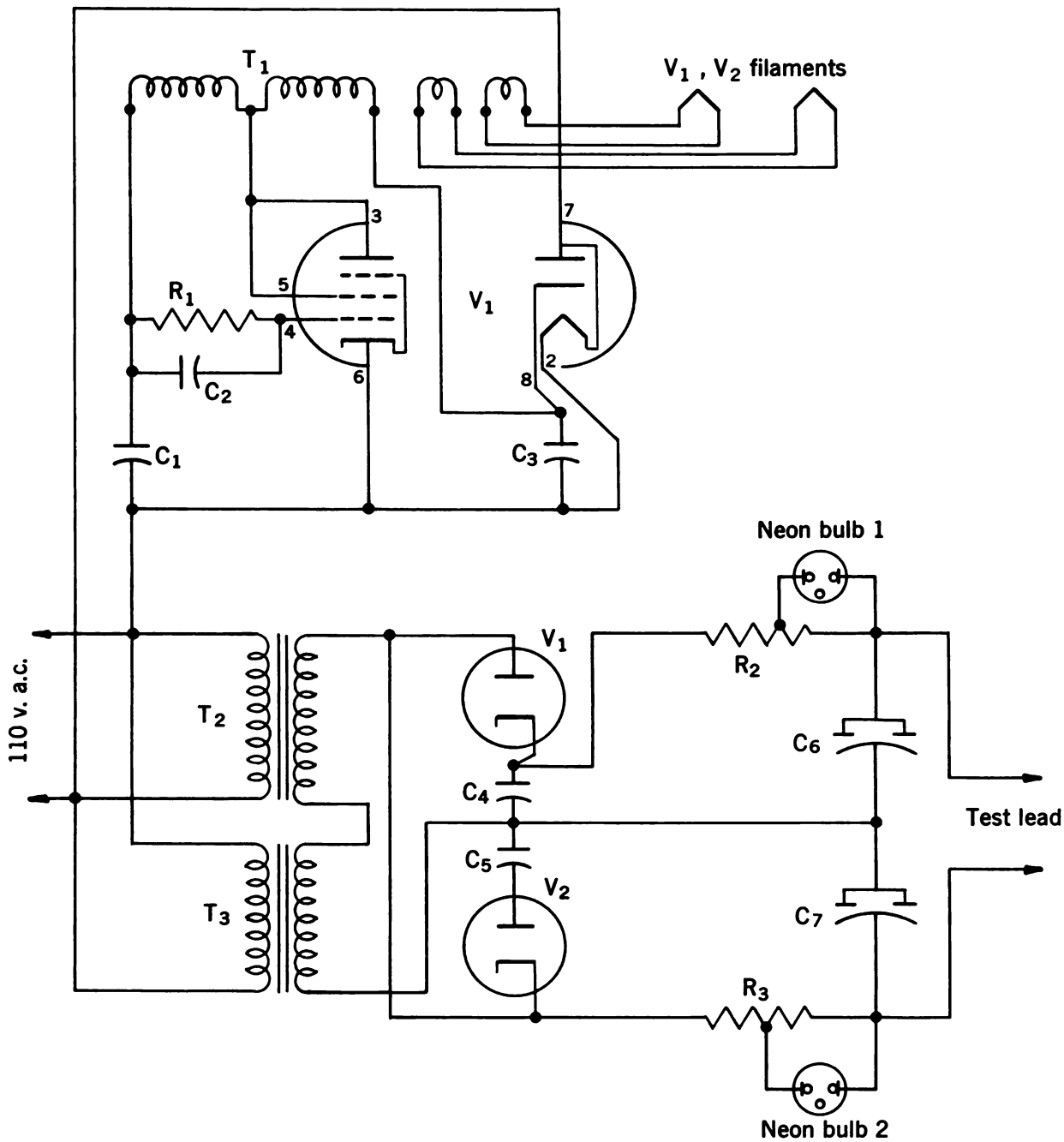

FIGURE 2. - High-Voltage Cable Tester.

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To those familiar with an electronic circuits, it is apparent that means other than an oscillator would achieve the desired result in obtaining the required 1.4 volts for the tube filaments without the disadvantages of an oscillator. Accordingly, another model of the tester was built recently, in which the circuit was modified by adding filament windings to the high-voltage neon type transformers. These windings, consisting of No. 18 plastic insulated wire, were spaced around the outside original winding, and the turns were added until the desired 1.4 volts was achieved.

The modified model has been tried and found satisfactory; however, since it has not yet been used extensively--the older model has been proved in performance--the discussion here and the circuit diagram (fig. 2) are confined chiefly to the older time-tried model. Other modifications will suggest themselves to the electronically minded; however, anyone interested in building a tester for practical use can be guided by figure 2, with the assurance that it will do the job and stand up indefinitely with minimum maintenance.

Test Procedures, 4,160-Volt Cables

The ohmic resistances across different cable faults may have any value from near zero upward over a wide range. No purpose would be served in the practical application of the test procedures to attempt to classify faults in brackets of specific resistance values. For this discussion, three loose categories of resistance have been set up--intermediate, low, and high. The test procedures are discussed in that order, since that is the logical sequence for making tests with the instruments described.

Test Procedure No. 1, High-Voltage Tester

The cable to be tested is laid on the ground, with the conductor ends separated, and kept free from earth contact. One of the test leads is connected to the cable ground conductor, and the other test lead to any one of the three-phase conductors. The tester is turned on and allowed to warm up for a few seconds. After the 0.2-microfarad capacitors are charged, they impress a potential of approximately 30 kilovolts on the insulation separating the phase conductor from the ground circuit in the cable. If a fault of intermediate resistance exists at any point, the cable insulation is defective, and an intermittent arc will be established across the weak spot, creating a staccato noise by which the fault can be located readily. Often, the arc is visible or will cause some smoke to appear. Each of the three-phase conductors is tested in like manner, and faulted areas are noted and repaired. Testing and repairing continues until the entire cable is in satisfactory dielectric condition.

This test is not too extreme; an ordinary two-conductor, No. 18 plastic appliance cord, used, but in good condition, will pass this high-voltage test. Thus, while the test procedure will locate cable faults, the 30-kilovolt potential will not destroy the 6,000-volt insulation. However, once the test current has found a weak point in the insulation, the cable must be repaired before again being placed in service, since the conductive path created by the test arc would also be conductive to the operating voltage, and an immediate

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short-circuit would result. This is an advantage of the test procedure, rather than a drawback, since the basic purpose of the special testers and tests is to insure that cables are maintained at all times in as near-perfect condition as possible.

The foregoing test will not detect faults of all types; for that reason, another means of detection is provided in the tester. Figure 2 indicates that a neon light is shunted across one of the 100,000-ohm, 2-watt resistors near the positive terminal and another near the negative terminal of the 0.2-microfarad capacitors. These lights are indicators, and they will light only when current is flowing through the resistor; consequently, if a cable is in good condition, the light will go out after the cable becomes charged. If the cable leaks, the charge on the 0.2-microfarad capacitors will bleed off through the fault, and current will flow through the current-limiting resistors to replenish the capacitor charge. The resultant voltage drop will keep the neon lights glowing. Continued glowing of the neon lights, however, merely indicates the presence of a fault; it does not locate it. If the lights indicate a fault, but test 1 does not produce a visible or audible arc, the capacitance charge is dissipated by shunting across the test terminals, and test 2 is made.

Test Procedure No. 2; High-Resistance Faults; Surge Test

If the foregoing test indicates but does not locate a fault, a more severe test is used. The conductor test lead is disconnected and placed about one-half inch from the faulted conductor, and both ends of this conductor lead are kept free from earth contact. The ground conductor of the cable is purposely grounded. The tester is then turned on, and the resultant surge through the spark gap breaks down and locates stubborn leaks by creating an arc that can be seen or heard; whereas the normal steady output of the high-voltage tester would not do so. Grounding the cable ground conductor is unnecessary to the test, but is introduced for added safety; it reduces greatly, but does not eliminate the capacitance charge that can be stored in the cable.

Test Procedure No. 3; Low-Resistance Faults; Low-Voltage, High-Current Test

Faults in which line-to-ground resistance is low usually will not be detectable by the procedures using the high-voltage tester, because as noted, the fault will bleed off the charge from the capacitors, so that enough voltage to establish an arc cannot be built up, even by the spark-gap surge procedure. To detect such faults, a tester that produces high current at low voltage was developed. It is described later in connection with testing ground-circuit continuity and effectiveness, for which it is also used. The test procedure is described here, however, to complete the group of tests required to insure that cables are in good condition with regard to insulation of phase conductors.

The two leads of the low-voltage, high-current tester are connected to the faulted cable conductors, and the maximum current produced by this tester (100 amperes at 10 volts) is passed through the cable. This causes heating at

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the cable fault, if the fault has some resistance, and the fault can then be located either by feeling along the cable for a warm spot or sometimes by the appearance of smoke. If the fault is of very low resistance relative to the normal cable resistance, the entire cable from the test device to the fault will heat and can be located by feeling along the cable. With the larger sized cables, such as the 2/0 or 4/0 distribution cable, it is sometimes necessary to use a high-current welder to locate faults of extremely low resistance, but such cases are rare.

Safety Warning, Use of High-Voltage Tester

The voltages used in the high-voltage tester are truly high, and the energy stored in the 0.4 microfarad capacitors could be lethal. If a cable is in good condition, the cable will act as a capacitor and could also be lethal if contacted. Extreme caution must be exercised while using the tester. The capacitors and cable should be discharged at the end of each test by shunting a low-resistance jumper across the terminals for an appreciable time, not just momentary contact. It is not necessary to handle the tester except when connecting to the conductors, and all points of contact are enclosed within the plastic case, except the clamp ends of the test leads. High-voltage rubber gloves should be used when connecting leads to cable conductors and when plugging the tester in an energized 110-volt source, as an insulation failure in the tester could put a lethal transient on the primary 110-volt current.

Equipment and Procedures for Testing Ground Circuit of 4,160-Volt Cable

Low-Voltage, High-Current Tester

Testing ground conductors in cables containing shields and several grounds with a conventional-type tester, such as an ohmmeter or ringer, is not dependable, since such instruments will indicate continuity, although the cross-sectional area of the ground conductor might be greatly reduced. If an accurate ohmmeter or other accurate instrument is used, the resistance could be measured and compared with tables to arrive at apparent current-carrying capacity; however, if the ground or grounds are broken, or partly broken, and the position of the cable holds the broken ends of the ground together, test results might easily indicate the ground circuit to be satisfactory, because of the low-current values involved. To circumvent the possibility of deceptive test results at the Tecumseh mine, a high-current, low-voltage, cable-testing device has been developed, so that the ground-circuit effectiveness in large cables can be dependably determined.

A 6-volt, portable battery charger is used (fig. 3). It is the quick charge type commonly used in automobile service stations, and is readily available commercially. It consists simply of a 110-volt primary stepdown transformer and a dry-type rectifier which delivers a low-voltage, rectified alternating-current, of relatively high value (in this case, 100 amperes). Some units of similar type deliver as much as 200 amperes. Current and voltage are indicated separately by a single meter equipped with a double-pole, double-throw toggle switch, and the switch is positioned to read amperes or volts. This tester is easily handled by one man.

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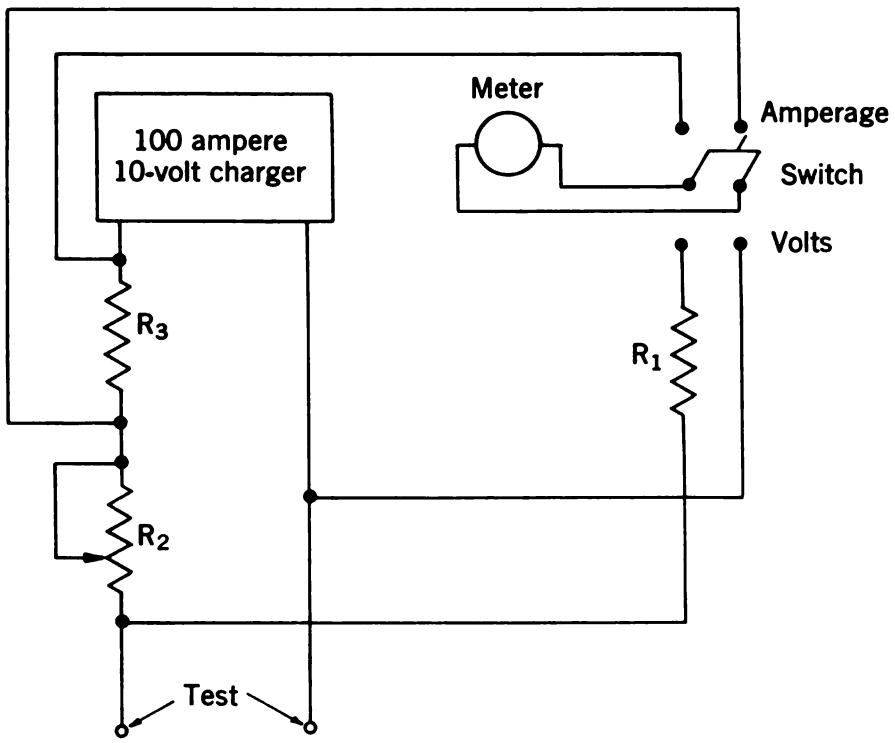

FIGURE 3. - Low-Voltage, High-Amperage Cable Tester.

Cable testing procedure is simple. The described ground tester is provided with two flexible insulated leads, to which are attached large alligator clamps. One lead is securely attached to the cable ground; the other test lead is securely attached to the ground at the other end of the cable. (At this mine all ground conductors and conductor shields are brought to a common connection and attached to a molded rubber plug or lug; short segments of cable that are not connected to plugs would have the grounds grouped together for testing.) Even when the cable is as long as 1,000 feet, the ends of the cable are dragged, so that both ends are accessible to the test leads. This doubling back is done instead of the simple procedure of tying power conductor ends to ground ends at the far end of a stretched-out cable, and then deducting the value for the power conductor, to avoid introducing a possible error should any of the power conductors be faulty.

The tester is turned on, the amperage and voltage noted, and resistance of the ground conductor is calculated by Ohm's law. The result is compared with standard resistance tables for a given wire size and length, and if this resistance is within a certain percentage of the table value, the cable is considered in good condition.

The percentage tolerance permitted is a variable, dependent solely upon the intended use for the cable. If the distribution system is a considerable distance from the transformer, the ground resistance of the cables is a large factor in keeping the equipment frames at a safe voltage in event of a line-to-frame fault. In such long lines, cable ground-circuit resistances must be kept to a minimum; therefore, a cable in which the ground conductor had decreased excessively in cross-sectional area might permit too high a frame-to-earth voltage in event of such a fault. In short transmission systems, the ground-circuit resistance of the cable is allowed a wider spread, because of the great difference between the cable resistance and the value of the ground resistor or impedance. At Tecumseh, cables are rejected for 4,160-volt service if calculations show that the frame of the portable equipment would exceed 100 volts under a line-to-frame fault.

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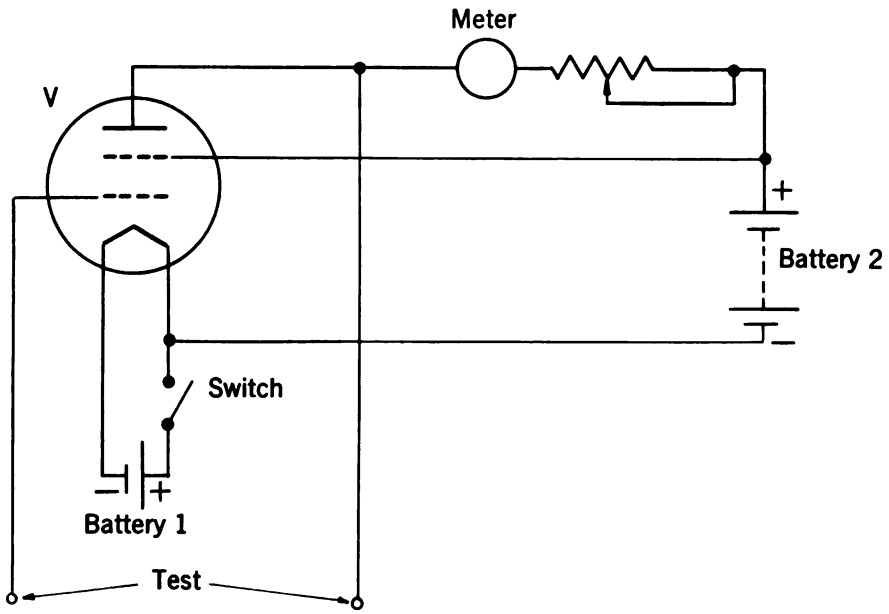
Equipment and Procedures for Testing 440-Volt Cables

Cables used on all 440-volt applications for portable equipment are the rubber-jacketed, three-conductor, type W, which is not provided with a separate ground circuit. Equipment frames are grounded by the electronic device described earlier. Cables are provided with molded rubber plugs on ends.

These cables are tested by use of an instrument especially designed for 440-volt cables and used for no other purpose. This instrument is essentially a vacuum-tube voltmeter housed in a plastic case, 3 by 3 by 7 inches, and weighing approximately 2 pounds (fig. 4). The meter has graduations from 0 to 550 in steps of 10. The unit is provided with two test leads, and has printed operating instructions mounted inside but clearly visible through the clear plastic case.



METER SCALE

Reading	Ohms
490	2.5 k.
460	15 k.
400	60 k.
350	150 k.
300	310 k.
215	1 meg.
160	3.3 meg.
120	10 meg.
70	26 meg.
50	50 meg.
40	90 meg.

FIGURE 4. - Vacuum Tube Voltmeter Type Tester for 440-Volt Cables.

Test Procedure No. 4, 440-Volt Cables

The 500-foot lengths of cable is disconnected from equipment and dragged to the nearest waterhole, and the entire cable with the exception of the extreme ends is immersed in the water. The meter is connected by clipping one test lead to all three cable conductors, and the other test lead is connected to the damp earth near the water's edge by clamping to a driven metallic rod. Ends of conductors at both ends of the cable are kept free from contact with the earth or water. The cable is slowly dragged out of the water by hand, and the meter is observed. When a leaky place in the cable is taken from the water, the meter reading will fall slightly, indicating location of the fault, which is repaired. The cable is thus tested (splices included) until the entire cable, while immersed, gives a reading of at least 150 on the meter

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scale (approximately 5 megohms) for an old cable. New cables are required to have a higher resistance. If the cable cannot be repaired to pass this 5-megohm test, it is junked.

CABLE SPLICING

Splicing methods at Tecumseh mine are generally conventional. They are described here in detail for completeness and to show that nothing is involved except good splicing procedures, plus a single new feature, a layer of rubber-and-nylon-cord ply material wrapped over the splice. This material adds greatly to mechanical strength of the finished splice and improves waterproofing, but its use requires no unusual preliminary steps. On the other hand, good workmanship throughout is essential, as the nylon cord alone cannot be expected to overcome the results of slipshod splicing of individual conductors.

Rubberized Nylon Cord Ply

This material is known to tire manufacturers as "nylon ply"; it is the material used for the plies in building the carcass of a rubber tire. The ply material is coated on both sides with an adhesive substance; one side is protected by fabric, which separates the plies in the bales, as shipped, and it should not be peeled off until just before the ply is wrapped around the splice.

In the available material, the nylon cords run in only one direction, and it is essential that the material be cut and wrapped around a splice in such manner that the cords are parallel with the major axis of the cable, in order that the extremely high tensile strength of the material will be utilized when the cable is under tension in mine service.

Splicing 4,160-Volt Cables, Type SH-D

Splicing is done in the following described manner:

1. Straighten cable for at least 20 feet each side of fault. This insures that all conductors will be the same length after being cut and rejoined, so that as the cable is later dragged in service, equal strain will be placed upon all conductors; this also helps prevent the outer jacket from opening under strain.

2. Saw cable, so that the cut is at right angle to the major axis of the cable.

3. Remove outer jacket completely for 8 inches from each side of the saw cut.

4. Taper and scrape (roughen) an additional 4 inches of outer jacket on each side.

5. Peel copper shielding braid off each phase conductor for 6 to 7 inches, leaving 1 to 2 inches for contact with gauze (see step 13).

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6. Remove enough conductor insulation on each side to accommodate splicing sleeve. The insulation should be cut at an angle (like sharpening a pencil); this prevents nicking the conductor, which might result in premature breakage.

7. Scrape remaining exposed conductor insulation for about 4 inches, removing all cloth but 1 inch or so beyond the braid left by step 5, so that friction tape may overlap this cloth layer.

8. Use splicing sleeve of proper size for size of conductor; insert conductor ends until they both touch the center stop. Indent with crimping tool at two points on each side--three points when sleeve length permits. Indent rather lightly near outer edges, first to anchor; then indent at next point or points toward center, increasing pressure progressively. Graduated pressure of indentations allows for wire flexing at the point where it emerges from the rigid splicing sleeve.

9. At Tecumseh mine, individual conductor splices are not staggered; some electricians might prefer to stagger splices, but this usually requires a longer splice, and if many conductors are involved, more care is required in keeping all rejoined conductors the same length to take the strain equally. The choice may depend upon whether a cable is to be reeled or otherwise flexed frequently; generally, flexing is a minor factor in strip-mine service.

10. Cover each splicing sleeve and anybare conductor with two layers of friction tape (ordinary black tape), but do not run tape onto tapered insulation left from step 7.

11. Apply rubber cement to the friction tape and also coat the scraped conductor insulation; then cover with rubber tape, building up to at least 1/2-inch in thickness over the sleeve, and tapering out to one layer at the end of the scraped conductor insulation near the cloth. Rubber tape is used for this purpose because mechanical stress, not dielectric strength, is the controlling factor in this case.

12. Cover each conductor with one layer of friction tape from cloth covering to cloth covering, so that it laps the cloth enough to cover any tears. All conductor insulation must be covered by friction tape or cloth or both.

13. Bend grounding conductors back out of the way, and wrap copper gauze firmly around the three-phase conductors as a group, so that gauze overlaps shielding braid left at each end in step 5. Secure each end of copper gauze with friction tape.

14. Join ends of each grounding conductor with splicing sleeves; leave sleeves bare to make contact with gauze.

15. Cover entire group of conductors and ground with one layer of friction tape so that friction tape covers all copper gauze and ground wires. The entire gauze must be covered with friction tape, as the cement used in the next step will cause corrosion of the fine copper wires in the gauze.

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16. Coat entire splice with rubber cement, extending the cement over the previously tapered and scraped 4-inch sections of cable jacket.

17. Cover with at least one layer of rubber tape, building up hollow places and generally smoothing out the splice to conform to jacket circumference as nearly as possible. Apply rubber cement over the entire splice.

18. Peel off protective fabric and cut nylon ply long enough to reach within one-half inch of each end of the rubber tape, cords running parallel with conductors, and wide enough to overlap and make a good water seal when wrapped around splice. Apply with adhesive side against cable, pressing down as it is wrapped to make a snug fit.

19. Cover with two or three layers of rubber tape and finish with three layers of friction tape.

20. Paint with insulating paint or varnish.

Splicing 4,160-Volt Wire-Armored Cables

The 4/0 armored cables are spliced in much the same manner as the SH-D cables, except that the conductive braid is omitted. The splice is finished, except for rejoining the armor, by wrapping it with two thicknesses of asbestos sheet or tape, which is applied to the last layer of friction tape and then covered with friction tape. A piece of 20-gage steel, about 4 inches wide, is wrapped around the center of the splice; and the armor wires, which had been previously clamped and bent back, are formed about the cable jacket and the splice and welded to the steel sheet. When the splice must be made on downtime, the armor is not welded but is bonded by a jumper, and the splice is raised above earth contact; it is later welded while out of service.

Splicing 440-Volt Cables

The 440-volt cables are spliced similarly to high-voltage cables, but the procedure is simpler, since only three conductors are involved in type W cable. The splice is wrapped with nylon ply, then with rubber tape and friction tape.

Repairing Jacket Punctures; 440-Volt Cables

The water-immersion procedure described in test 4 will locate any jacket puncture that has penetrated to a conductor. Jacket punctures (not defective splices) are repaired by cleaning the cable, coating with rubber cement, wrapping with rubber tape, and finishing with a layer of friction tape.

Time Required

The foregoing splicing procedures require the following approximate times by one man: For 2/0 SH-D, 1-1/2 hours; for No. 4 SH-D, 50 minutes; for 4/0 wire-armored, 1 hour to splice and 3 hours to weld; and for No. 6, type W, 20 minutes.

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Friction Tape

To those not familiar with splicing high-voltage cables, the reason for interspersing layers of friction tape may not be apparent. Friction tape will adhere to bare metal better than rubber tape, and the rubber tape will then adhere well to the friction tape. As for the other layers of friction tape, the friction tape is a poor dielectric material for high voltage; in fact, it becomes a semiconductor under high-voltage conditions. This semiconducting characteristic minimizes the corona effect, which would otherwise create ozone and destroy the rubber insulation. It is essential that all bare copper around sleeves be covered with friction tape to prevent corrosion from the rubber, and that all bare rubber insulation on conductors be covered by friction tape to overlap the cloth layer.

Advantages of Described Splicing Methods

The following claimed advantages are based entirely on actual experience as reported from the Tecumseh mine:

Strip mine cables must be moved frequently. They are usually relatively long; therefore, total weight is great in any conductor size, and they must be dragged by horses or, now more commonly, by mechanical means. Mechanical strength of splices is, therefore, as important as adequacy of insulation. The nylon ply has not been used at the Tecumseh mine long enough to assess its capabilities; in several instances, cables have been strained so severely that the cable parted at a solid place, whereas a nearby nylon-ply-covered splice remained intact. This has occurred with cables of different sizes.

Imperviousness to water is another essential need in splicing strip-mine cables. In wet work, as in pumping service, and in general pit work during wet weather, the Tecumseh maintenance staff reports that virtually no more downtime results from failure at splices than is experienced in dry weather, which is somewhat different from the experience at most strip mines. Cable age ranges to 16 years for wire-armored cables and from 4 to 10 years for SH-D cables.

The splicing methods provide all three essentials--adequate insulation, mechanical strength, and water-tightness. The methods require somewhat more time and materials than slipshod methods, but considering the long life and freedom from trouble of the resulting splices, the overall cost is much less than for less meticulously made temporary splices. Downtime from phase-to-phase or phase-to-ground faults is rare.

The current practice at Tecumseh mine is not to vulcanize splices, since the temporary splices with the nylon-ply virtually have eliminated all splice troubles.

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PARTS LIST FOR ELECTRONIC GROUND DETECTING DEVICE
(Fig. 1)

V1 - 50Y7GT full-wave rectifier tube.
V2 - 12AU7 time-delay tube.
V3 - 50L6 resistance measuring tube.
R1 - 100 ohms, 20-watt, filament voltage dropper.
R2 - 100,000 ohms, 2-watt.
R3 - 2 - 100 K., 2-watt, in parallel.
R4 - 22,000 ohms, 2-watt.
R5 - 9,000 ohms, 10-watt.
R6 - 7,000 ohms, 5-watt.
R7 - 22 megohms, 1/2-watt.
R8 - 27,000 ohms, 1/2-watt.
P1 - 10,000 2-watt potentiometer.
C1 - 20 mfd., 450-w.v. electrolytic.
C2 - 8 mfd., 450-w.v. electrolytic.
C3 - 0.02 mfd., 600-volt.
C4 - 0.1 mfd., 600-volt.
C5 - 1.0 mfd., 600-volt.
Rel. 1, rel. 2, 10,000 ohms, SPST relays.
Rel. 3, 115-v.a.c., DPDT relay.
L1, L2, L3, L4 filter chokes (Thordarson 20C50) used to establish a.c. neutral and to filter out transient a.c.
T1 - 4,160/440-volt power transformers.
T2 - 0.1 kva, 440/110 volt dry-type transformer.
Light - 50-watt, 110-volt (filament type), used to indicate when unit is in fault position.
SW - SPDT toggle switch, used for test and normal operating conditions.
SW1 - Main 440-volt, magnetic-type power switch.
NE - NE2.

PARTS LIST FOR HIGH-VOLTAGE CABLE TESTER
(Fig. 2)

V1, V2 - 1B3GT high-voltage rectifier tube.
V3 - 117N7GT dual-section tube, used as an oscillator and rectifier.
R1 - 10,000 ohms, 2-watt.
R2, R3 - Each consisting of twenty 100,000-ohm, 2-watt resistors in series.
C1, C2 - 0.001 mfd., 600-volt.
C3 - 30 mfd., electrolytic, 250-w.v.
C4, C5 - 500 mmf. (high-voltage television type).
C6, C7 - Dual-section, 7,000-volt, oil-filled, 0.2 mfd., each section.
T1 - 110/5,000-volt neon transformer.
T2 - 110/6,000-volt neon transformer.
T3 - Motorola TV, high-voltage transformer, with two filament windings added (four turns) for V1 and V2. (High voltage coil removed.)
Note: The high voltage secondary windings of T1 and T2 must be reinsulated from winding to ground to withstand high voltage from doubler circuit.
NE1, NE2 - These are NE2-type neon gas-filled tubes, each one shunted across one of the series-connected, 100,000-ohm, 2-watt current limiting resistors.

PARTS LIST FOR LOW-VOLTAGE, HIGH AMPERAGE CABLE TESTER
(Fig. 3)

100-ampere, 10-volt charger; converted from garage, dry-rectifier, quick-type, auto-battery charger.
M - 0 - 500 microampere meter.
SW - DPDT toggle switch.
R1 - Dropping resistor, value of which allows M to read full scale at full output voltage of rectifier.
R2 - Current limiting resistor, 100 ampere or larger with variable shunt, to allow a few amperes with all the resistance in to a maximum of 100 amperes with all the resistance out.
R3 - Meter shunt, consisting of a short strip of metal with meter terminals at ends.

PARTS LIST - VACUUM-TUBE-VOLTMETER-TYPE 440-VOLT CABLE TESTER
(Fig. 4)

V - 1U4.
M - 0 - 500 microampere meter.
B1 - 1-1/2-volt filament battery.
B2 - 22-1/2-volt plate battery.
SW - STSP toggle switch.

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